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【論文の内容の要旨】

In distribution warehouses, work efficiency improvement is required to deal with increased shipping. In order to achieve work efficiency improvement, it is necessary to analyze workers' movements and ameliorate and automate their inefficient movements. What has been developed as warehouse management technologies for this purpose includes a sensing technology that uses image processing, radio waves and ultrasonic waves for the automation of movement analysis and a sensing technology that uses image processing for the automation of shipping volume inspection by the eye in order to shorten working hours and prevent shipping errors. However, the conventional methods while using sensing technologies have a defect since they do not take generalization ability of the estimation models into account. They provide good estimation performance from sensed past learning data, but they make large estimation errors in respect of unknown inspection data.

In this thesis, we propose a method aimed at improving the generalization ability of estimation models used in sensor systems for warehouse management. Based on optimization theory, system configuration and measurement/estimation models are designed according to functional requirements and environmental limitations. Considering realistic demand for warehouse management, sensor systems for indoor positioning, work analysis automation and counting automation are evaluated. This thesis is divided into five chapters:

Chapter 1 reviews the available research on the sensing technology used in logistics centers and describes common applications. The purpose and significance of the current studies are then presented, and the organization of the thesis is outlined.

Chapter 2 introduces the proposed method for measuring the position of workers or products inside a facility using RFID. The main problem with using RFID to track indoor positioning is caused by multipath, which significantly reduces the accuracy of position estimation. Consequently, the proposed method seeks to reduce the adverse influence of multipath. In the proposed method, one or more tags can always be detected if multiple tags are attached to the target at different height. While varying the position of the positioning target, the reading rates for the tags can be obtained. A data set composed of the reading rates as input data and the positions of the positioning target as output data is then constructed. Using the generalization error as an index, an effective mathematical model for estimating the position of the positioning target from the input data is obtained. In an application example, the maximum value of the position estimation error for a stationary target was shown to be within 1.0m. Moreover, the height of the positioning target could be accurately estimated at all measuring points if the height difference between tags on the positioning target was at least 0.8 m. In a flow line investigation in which the target to be measured moved, the maximum value of the position estimation error was shown to be 0.5 m or less.

Chapter 3 describes the development of a work analysis support system for distribution processing and presents a case study featuring a retail clothing order fulfillment center. In this system, multiple ultrasonic sensors are used to measure a worker's flow line, and a smartphone is used to measure the worker's dominant hand acceleration. Models for estimating the worker's motion were derived from the obtained data. Candidate estimation approaches included the linear discriminant model, decision tree analysis, neural network and the k-nearest neighbor algorithm. The generalization error using cross-validation served as an index for choosing the optimal model. The support system obtains the described apparatus and methods for automating work analysis. The system was applied to an order-picking example at a clothing distribution center. The result of consistency test between the results obtained by video analysis and by support system was represented by kappa coefficient (κ). The value of κ was higher than 0.6, indicating that the work analysis result using the proposed system was acceptable.

Chapter 4 describes two methods and an apparatus for automatically counting the number of stacked plywood sheets. The first method is a comparative method using image processing. Based on the normalized cross-correlation (NCC) method, this method can be used to detect plywood sheets, piece by piece. The second method is the proposed method. This method is based on the cross-validation method and uses an estimation model to determine the central portion of each plywood sheet in the cross-section. While using the proposed method, three candidate estimation approaches were evaluated: a statistically determined linear discriminant function, a decision tree, and a neural network, and the generalization error by cross-validation served as an index for choosing the optimal estimation model. In the application example of measuring about 450 to 500 common stacked plywood sheets with a standard thickness of 2.4 mm, both methods were able to correctly counting the number of plywood sheets. However, compared to the comparative method, the proposed method based on estimation model could significantly reduce the time required for counting.

Chapter 5 summarizes the findings of the study and proposes areas for further research. The expectation of improving generalization performance in actual logistics centers using the proposed method is discussed.